Transition to Hydrogen with NGV Technology

Natural Gas Vehicle Technology Forum

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Westport INNOVATIONS INC.

Westport's Gaseous Technology

- Cummins-Westport and Westport have evolved gaseous fuel technology for several natural gas engines.
- Base NG technology:
  - Low pressure fuel: Otto-cycle /single point mixing in intake manifold for spark-ignited engines.
  - Higher pressure fuel: diesel-like / late-cycle direct injection with ignition assist
    - Diesel pilot
    - Hot surface ignition
    - Spark ignition (future option)
- NGV Technology can definitely be used for Hydrogen Internal Combustion Engines (H_2–ICE)

Key Hydrogen Properties / Behavior in Engines

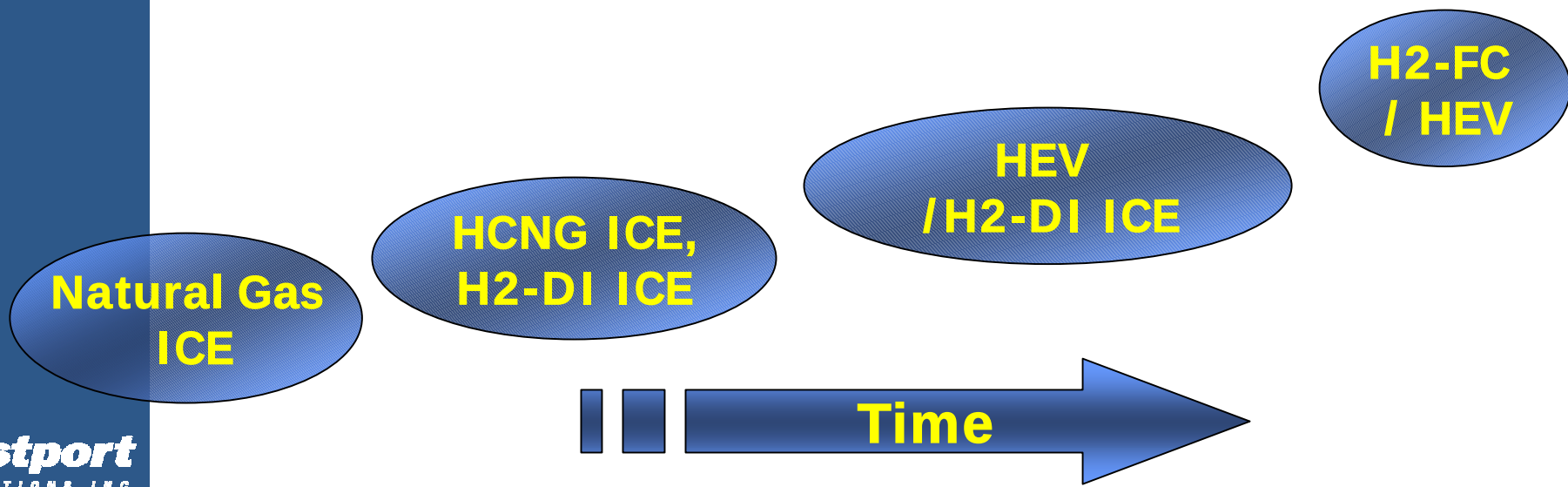
- **Hydrogen Properties**
  - Low ignition energy (1/10 of that for gasoline).
  - High flame speed (9 times that of gasoline).
  - Very broad flammability range (allowing unique potential for emission control) .
  - Lower volumetric energy density/high speed of sound

- **Hydrogen Engine Characteristics:**
  - Tendency to pre-ignite during compression.
  - Very fast burning rates.
  - Very low temperature combustion possible.
  - Fuel injection system requires ~20% larger flow area as compared to CNG
  - **For external mixing of fuel:** Theoretical loss of up to 30% air flow due to volumetric displacement by H_2 in intake manifold/cylinder.

Rationale for H2 ICE Technology

Engine technology roadmap

- Internal combustion engines (ICE) are very well developed and increasingly sophisticated.
- There is a pipeline of efficiency improving technologies that can still be used.
- Adapting high efficiency ICE's to hydrogen/natural gas mixtures or to hydrogen would result in very cost effective power plants for near to medium term.
- ICE development would be part of a long term H_2 roadmap:



Westport and CWI Primary Markets/Partners

CNG - Transit Bus

Cummins Westport

LNG - Heavy Duty Truck

Cummins MAN

CNG - Power Generation

Cummins

CNG - Medium-Duty Truck

ISUZU

Hydrogen Research

Ford

BMW

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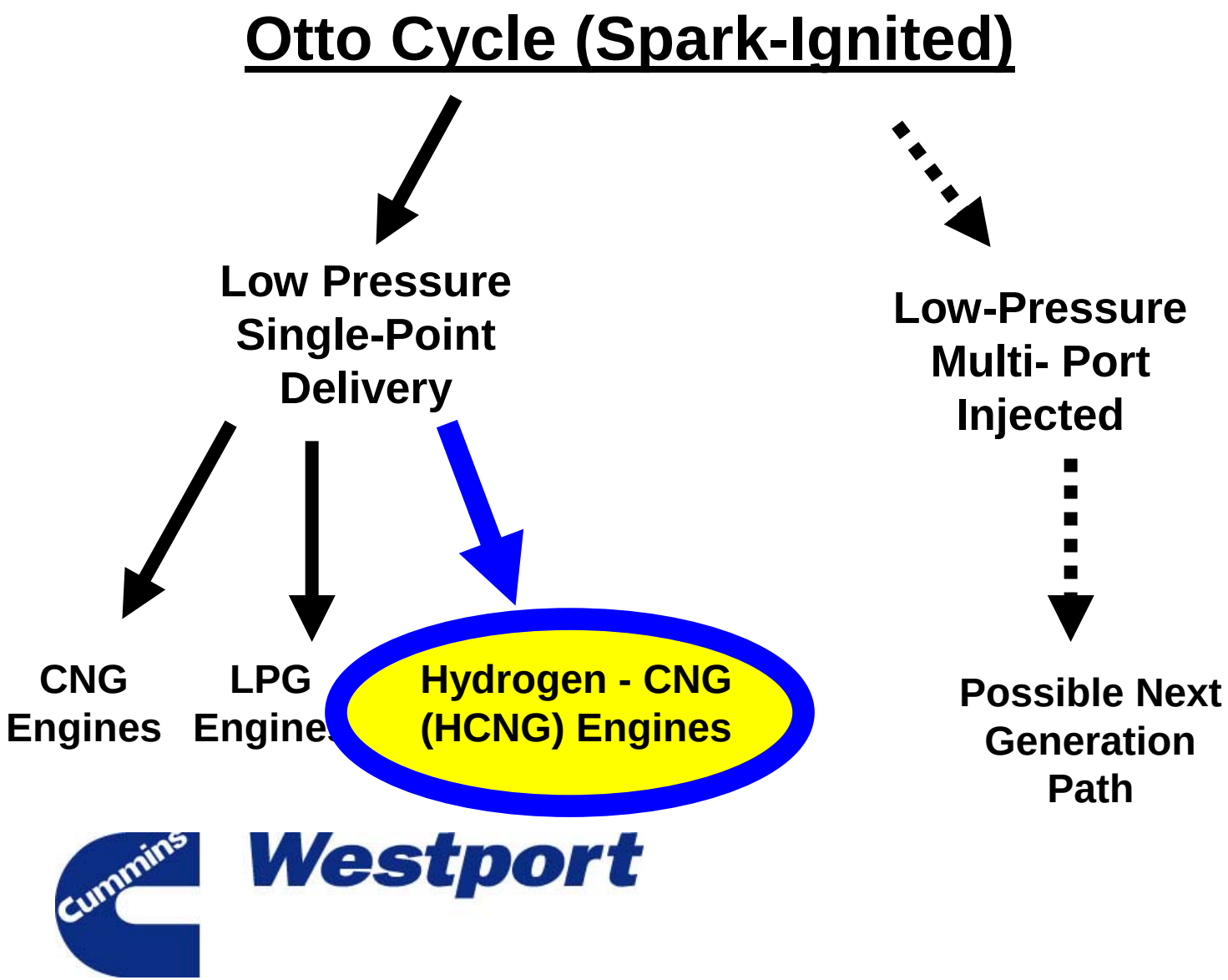
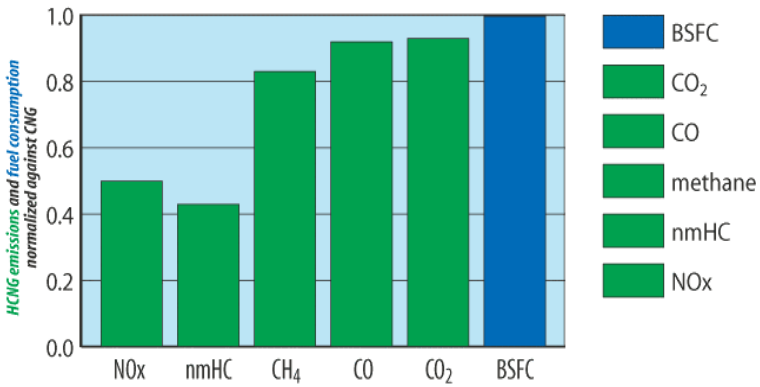
Low Pressure Technology Applications



HCNG: SunLine Transit Demonstration

- CWI 230HP, 5.9L spark-ignited lean-burn B Gas Plus natural gas engine modified to operate on an optimized HCNG fuel blend
  - 20 vol% H_2 / 80 vol% CNG
  - 230 hp / 500 lb-ft (replicates base engine)
- Transient emissions testing of the four buses
  - NOx & nMHC reduced by ~50%.
- Energy consumption unchanged. CO2 reduced by 7%.
- Duration: 2002 – 2004
  - 65,000 vehicle-miles in field trials for 2 HCNG buses
- Funding: NREL (U.S. DOE), South Coast AQMD



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HCNG: 4 Buses in Vancouver (2005-2008)

- Upgrade/calibrate CWI 280HP 8.3L C Gas Plus engines for HCNG.
- Hydrogen for HCNG via capture and purification of waste hydrogen (sodium chlorate plant).
- Potential to be showcased as part of the B.C. Hydrogen Highway Initiative.

- IWHUP (Integrated Waste Hydrogen Utilization Project) is an $18,000,000 initiative to harness recycled waste hydrogen
- Industry/Canadian Government Partners:

- Sacré-Davey Engineering
- Westport Innovations
- BC Hydro/Powertech Labs
- Clean Energy
- Dynetek Industries
- Nuvera Fuel Cells
- QuestAir Technologies,
- ERCO Worldwide
- Natural Resources Canada - CTFCA
- Sustainable Development Tech. Canada (SDTC)
- Industry Canada - TPC H2 Early Adopters

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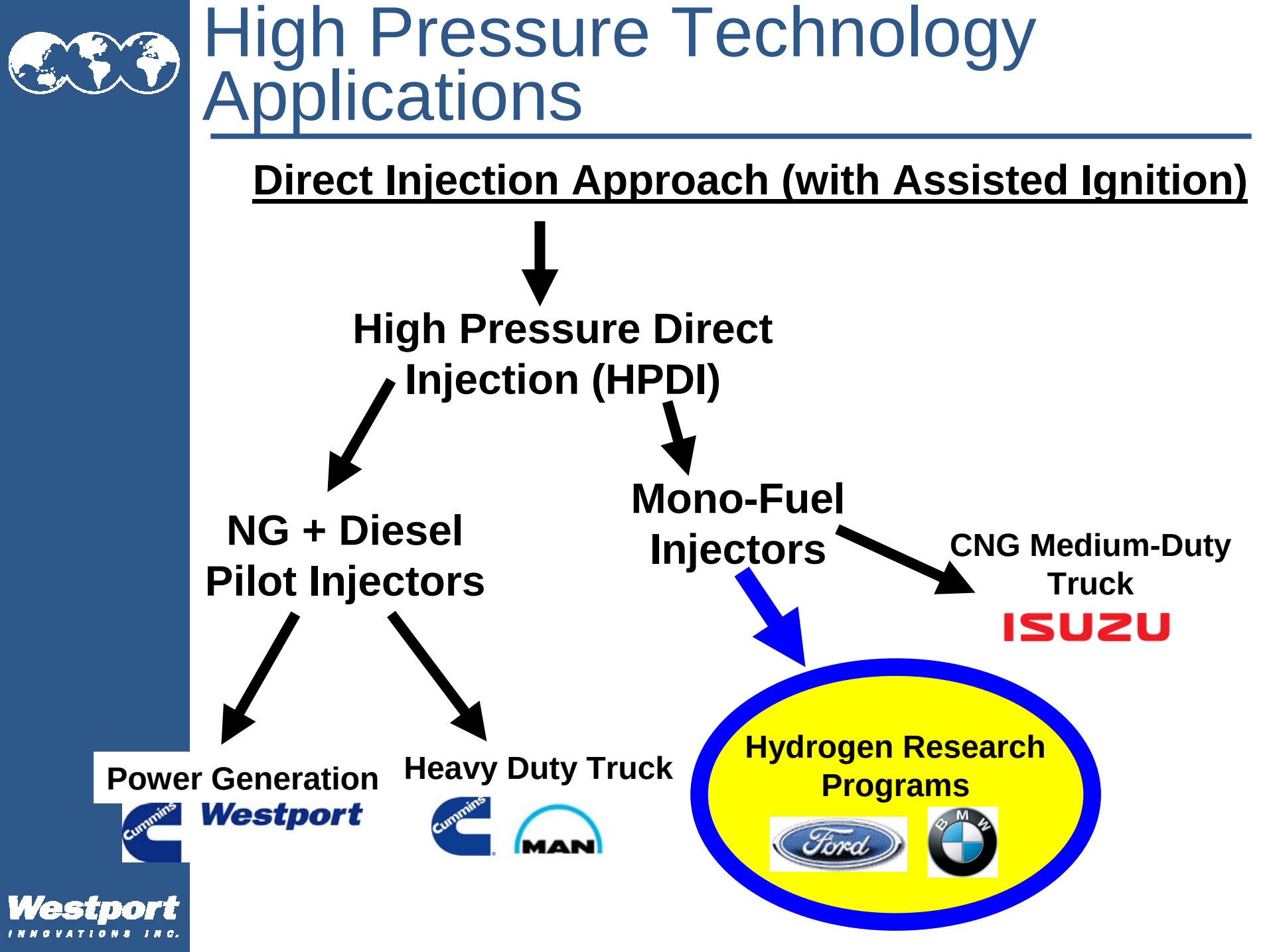
High Pressure Technology Applications



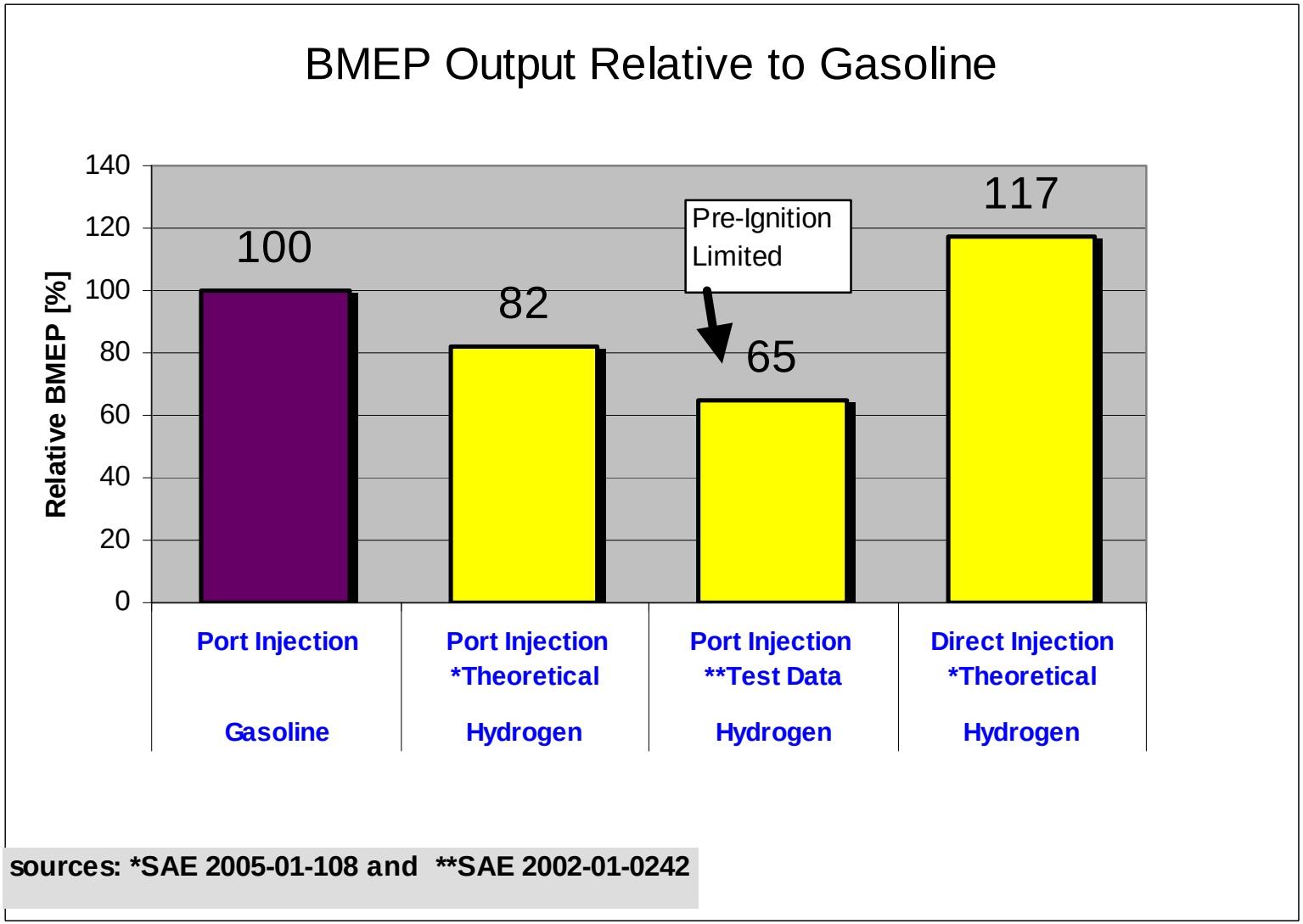
100% Hydrogen: Internal Combustion Engines

- **Options:**
  - Low pressure port-injection (generally limited by pre-ignition)
  - High pressure direct injection (diesel-like benefits)

- **Strong interest** from Ford* and BMW* in direct injection due to:
  - Eliminates hydrogen backflash or pre-ignition
  - Allows high CR> 14
  - High efficiency
  - High power density
  - Low emissions potential (with proper control).
  - near term opportunities for ICE's to support hydrogen economy and compliments fuel cell efforts.

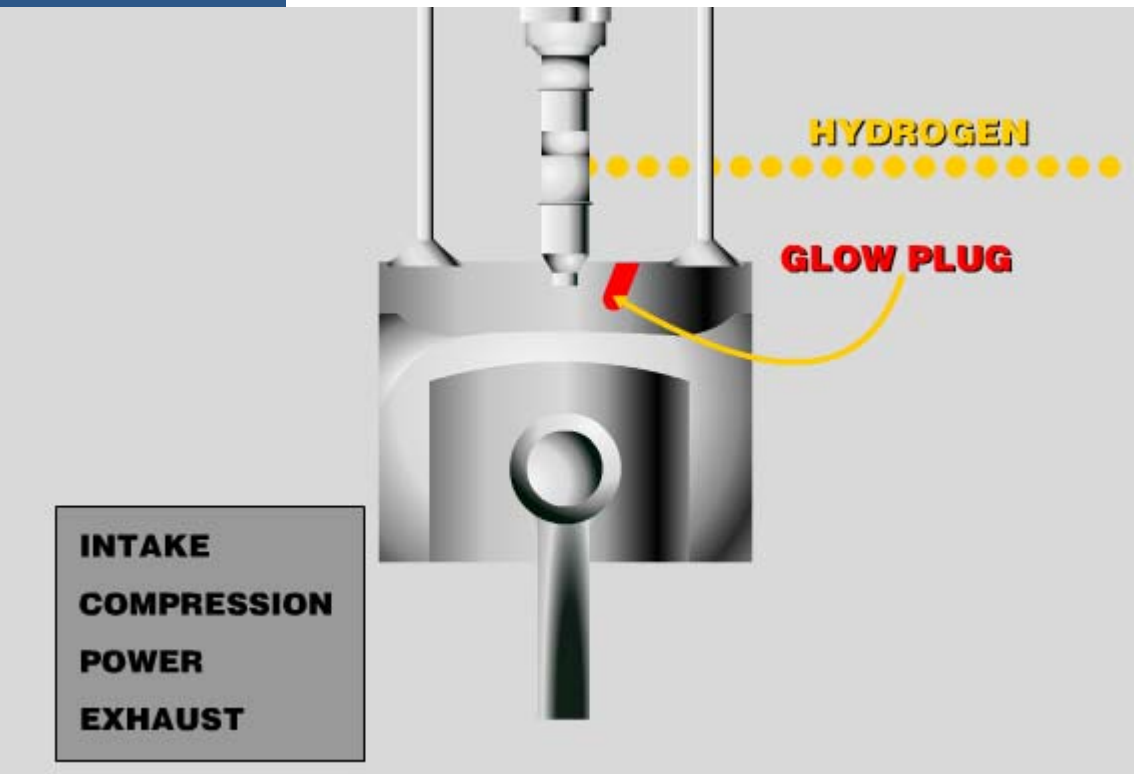
*several SAE papers are available

H2 Direct Injection - High Torque /Power Potential



sources: *SAE 2005-01-108 and **SAE 2002-01-0242

Direct Injection Technology

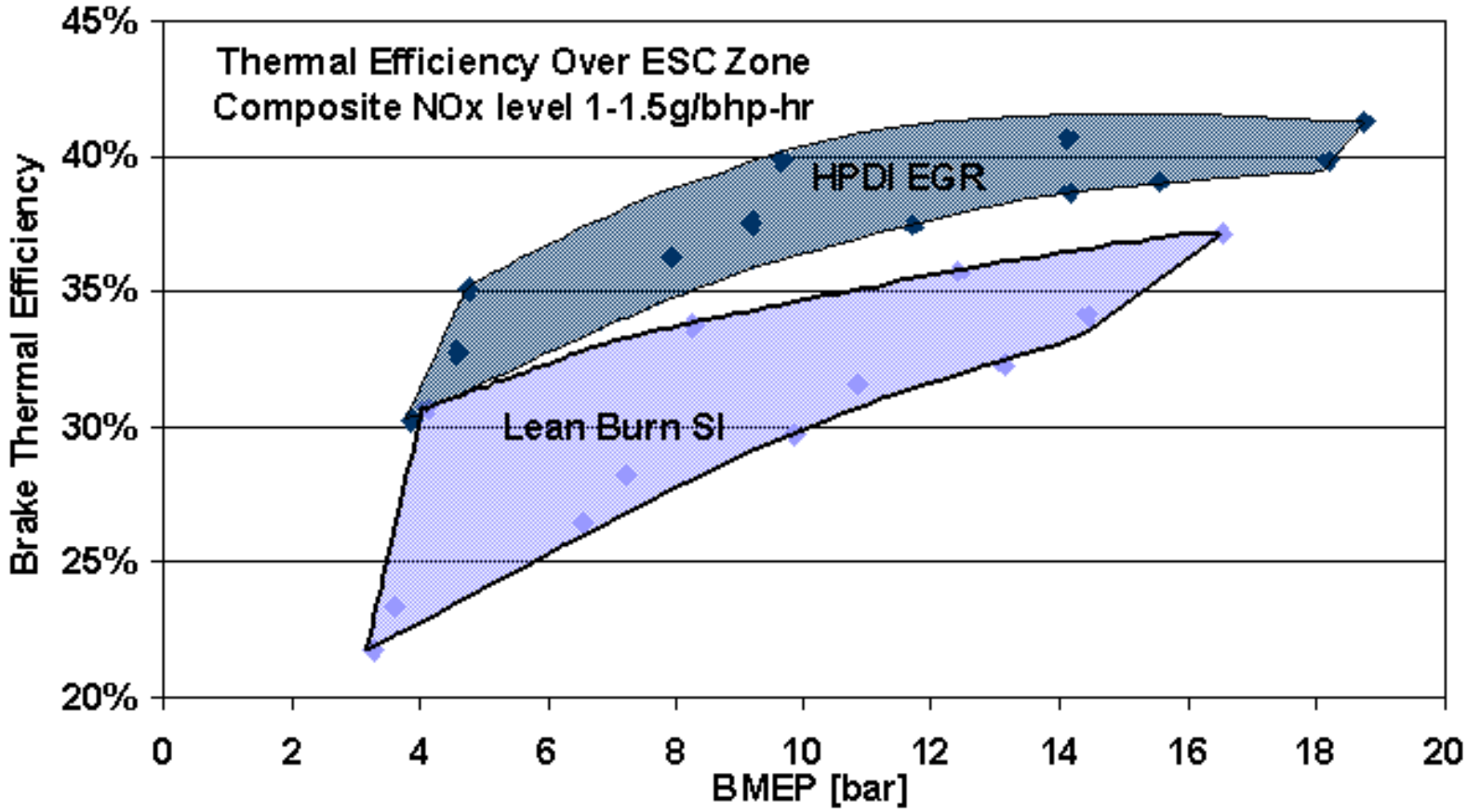


High Pressure Direct Injection (HPDI)

Mono-Fuel Injectors -used by Isuzu (NG) and Ford, BMW (H2)

NG + Pilot Diesel Injectors

Direct Injection Efficiency Advantage (CNG Data)



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H2 Direct Injection - Emissions

- At vehicle, green house gases (CO_2) are essentially eliminated
- Hydrocarbons and carbon monoxide are virtually zero.
- Oxides of nitrogen (NOx) can be controlled to ultra-low levels using very lean strategy, EGR and if necessary, NOx traps/aftertreatment.

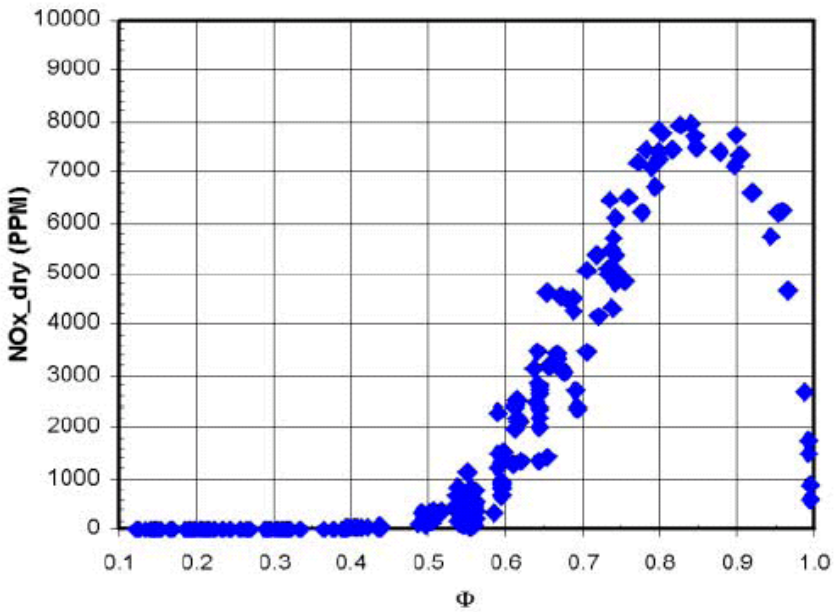

Figure 14. NO_x concentration vs Φ

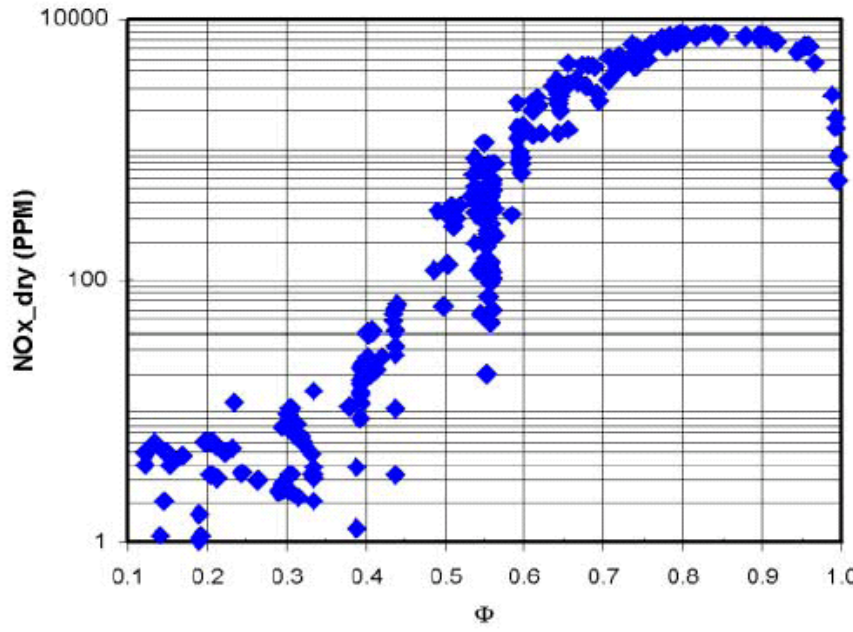

Figure 15. Log NO_x concentration vs Φ

*SAE paper 2002-01-0242 (Ford)

Summary Benefits of H2 Direct Injection

- H_2 DI eliminates pre-ignition
- High Torque (BMEP) and Power
- High Efficiency (Diesel-like)
- Low NOx potential (with proper control)
- Virtually zero HC, CO and CO_2

Conclusions

- CNG based technology can be definitely leveraged to effectively use hydrogen in ICE's.
- HCNG technology has allowed us to put early stage hydrogen technology on the road.
- Early H2-ICE DI work shows significant technical benefits / potential and will likely be the best path forward.
- Advanced hydrogen DI technology can provide excellent hydrogen ICE performance and emission characteristics.
- Close collaboration between industry and government is essential to move technology forward.